Abstract: - The new bus for home automation specified to use by microcontrollers is defined in the paper. The bus is designed for implementation in exist 100 BASE-TX Ethernet CAT-5e cabling. The bus specification is based on some home automation standards and combines theirs properties. The bus was named SoftBUS. SoftBUS use two twisted pair wires and both wires are exchangeable. Voltage levels on the bus are fully compatible with CMOS logic. Maximal defined speed is 1 Mbit/s (cable length 10 m). Bus speed can be easy changed. Bus specification effectively controls collision by bus state monitoring. Bus can operate in two modes – speed setting and data transmission. The communication frame consists of device address and data section. Because, there is intersection of the link and net layer of OSI ISO model [7]. The communication frame has variable length depending on device type but limited to 1 kB.

Key-Words: - Home automation, half duplex bus, CAT-5e cabling, SoftBUS

1 Introduction

Even if, the number of home automation buses exist (e.g. [1], [2], [3]) at present time, they are usually unusable because of their proprietary character and licences. The specification of described new bus arises during the diploma work solution. The work was focused on non expensive home automation system with central control point and sensors and controlling devices net. The crucial requirement for developed bus was its easy implementation by microcontrollers and simultaneously its wide use. The second main requirement, that conditions physical quality of the wirings was using present structural cabling of 100 BASE-TX Ethernet implemented by CAT-5e UTP cables. The specification was created on basis of the TWI [5], CAN [6], C-Bus [3] and partially from Ethernet [] buses. The decisive parameters were data transfer speed, reliability and low communication overhead costs during bus specification. The developed bus specification describes physical, link and even net layers of the ISO OSI model [7].

2 SoftBUS specification

As mentioned above, the bus planned deployment was in home automation. The bus was named “SoftBUS”. We consider the fact if the home automation should be wide applicable, it must not be much expensive. Due to, the developed bus was specified for implementation by simple (and cheap) 8bits microcontrollers with minimal external devices. One pair of twisted wires of the Ethernet 100 BASE-TX CAT-5e UTP cable was specified to use as a physical wiring of the bus. The maximal specified length of the bus is up to 100m. Bus specification describes three fundamental layers of the OSI ISO model [7] - physical, link and net. Unfortunately, intersection of the link and net layers is so noticeable that the separation into mentioned two layers is impossible. Additionally, in some cases, the intersection of the physical and link layer can be observed as well.

Characteristic attributes of the bus:

- Half-Duplex asynchronous serial bus,
- Peer-to-peer device connection
- Variable bus speed for better environment adaptation
- Defined bus speed up to 1 Mbit/s (cable length to 10 m)
- Specified length of the bus segment up to 100 m
- Effective collision controlling by bus state monitoring
- Variable frame size, but limited to 1 kB
- All devices addressing together possibility by General Call
- Addressed device exist/ready acknowledgement
- Frame receive acknowledgement
- CMOS logic compatible
- Designed for use in exist 100 BASE-TX
Ethernet CAT-5e UTP cabling

- Complementary signal lines
- Signal lines polarity independence
- Minimum external devices

3 Physical layer of the SoftBUS

SoftBUS primarily uses one pair of the twisted wires of the CAT-5e UTP cable for data transmission. The CAT-5e UTP cables are commonly used for 100BASE-TX Ethernet. Main parameters of the physical medium are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit with tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impedance</td>
<td>100</td>
<td>Ω ± 15%</td>
</tr>
<tr>
<td>DC resistance</td>
<td>9.38</td>
<td>Ω / 100 m</td>
</tr>
<tr>
<td>Propagation delay</td>
<td>4.8-5.3</td>
<td>ns / m</td>
</tr>
<tr>
<td>Mutual capacitance</td>
<td>5.58</td>
<td>nF / 100 m</td>
</tr>
<tr>
<td>Capacitance unbalance</td>
<td>160</td>
<td>pF / 100 m</td>
</tr>
<tr>
<td>Inductance</td>
<td>525</td>
<td>nH / m</td>
</tr>
<tr>
<td>Maximum current per conductor</td>
<td>0.577</td>
<td>A</td>
</tr>
</tbody>
</table>

Tab. 1: Selected parameters of the CAT-5e UTP cable

There are pull-up resistors on the data lines like in case of the I2C [4] or TWI [5] buses. The value of the pull-ups resistivity should be in range 30 - 60 Ohms. Data lines are grounded (set to log. 0) by transistors during communication.

Two complementary data lines are used for communication via bus. The change on the data lines presents logic 1. If there is no change on data lines the log. 0 is transmitted. Due to, the data lines are fully interchangeable. If there is no communication on the bus, both of data lines become into 5 V.

3.1 Data transmission over SoftBUS

There are defined two bus modes. The device can set bus speed in the first mode and send data at the second. Data transmission is initialized by sending START condition. The one data line is grounded while the second is left at high level.

![Fig. 2: Communication frame with START and STOP conditions](image)

Fig. 2: Communication frame with START and STOP conditions

Next, during the data transmission voltage levels on both of data lines are changed together when log. 1 is transmitted and stay in previous state when log. 0 is transmitted. Termination of the communication is signalized by STOP condition. One of the data lines is in high voltage level and the second goes from zero to high voltage level as well during STOP condition. There is graphic description of the data transmission in Fig. 2.

3.2 Communication speed

Maximal reachable communication speed is strongly depends on the cable length, number of devices on bus and on environment where the cabling is installed.

![Fig. 1: Microcontroller recommended connection to SoftBUS](image)

Fig.1: Microcontroller recommended connection to SoftBUS

The voltages of the SoftBUS logical levels were chosen accordingly to direct 5V CMOS circuit interconnection. Nevertheless, the value 5V of the line state high is only recommended and SoftBUS can operates with other voltages (eg. 3.3 V or 12V). If alternate operation voltage is used, the transmission parameters are also different.
The communication speed was set depending on the bus length in basis of the laboratory measurement. Measured curve is showed in Fig. 3.

3.3 Communication speed change
Bus speed setting mode is initiated by CLOCK SET condition. Next, device generates few clocks (5-10) on one data line while the second is grounded. This process set communication speed. Amount of generated clocks depends on bus speed. After communication speed is set STOP condition is generated. Bus speed changing is showed in Fig. 4.

3.4 Acknowledgement
There is very strong intersection between physical and link layer in case of the acknowledgement. There are two acknowledgements during the frame transmission. First, when frame head is send and addressed device acknowledges its presence and ability to start communication and data receiving. The second acknowledgement comes after all of data is transmitted and addressed device acknowledges receiving correct data. Then the STOP condition is generated independently on acknowledgement result.

If target device does not confirm its existence or ability to receive data, the transmitting device has to stop transmitting and release bus by generating STOP condition. The device should decrease bus speed before next transmitting and that enables addressed device receiving. There is another possibility to set bus speed. It is described in chapter 4.3.

3.5 Collision on the bus
The devices are parallelly connected to the bus and communication over bus is asynchronous. Due to, the collisions should appear accidentally. The collision recognition is crucial to its effective solving. There are many approaches to bus collision solving [4], [5], [6]. The collision solving on SoftBUS is based upon the CAN [6] bus.

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1 CAT-5e cable with transmitter and receiver

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Because, the two modes of bus operation are specified, there are two cases when collision can appear. In first case the collision should appear during bus speed setting. When two or more devices tries set bus speed simultaneously, bus speed is set to the slowest speed. This discriminating property is caused by physical realization of the bus.

The second case when collision can appear is during device addressing. At this point the link and net layer are intersected. The address of the target device is transmitted on the SoftBUS in communication frame. Transmitting device tests bus state permanently. If device finds out, that bus state not corresponds with set value, stops transmitting. So, the collision on bus is detected this way. The described situation is showed in Fig. 6. The communication priority between devices follows of device type defined in link layer.

![Fig. 6: Collision occurrence during data transmission](image)

The transmitting device must wait at least 5ms after successful communication to provide equally bus sharing before new transmitting. Devices which were in collision try start new transmit data after time defined by following equation

\[ n/S, \quad (1) \]

where \( S \) represents actual bus speed in bits per second and \( n \) is random number between 10-50, which is generated by device. The collision solving system is the same like in Ethernet specification. There is only difference in timing.

4 Link layer

The SoftBUS efficiency increase fact that data frame size is not fixed but depends on device type and amount of data. Nevertheless, the data space in communication frame is restricted to 1024 bytes. The value is sufficient for every device types connected on bus because planned using of the bus is by microcontrollers.

4.1 Data frame

Data frame can be separated into two relatively independent parts. As mentioned above in physical layer description, communication is initialized by START condition. Next, the six bytes of the device address are transmitted. The device address consists of one byte which defined device type, 3 bytes which identify vendor of the device and 2 bytes own address. Theoretically, above 60th thousand devices of same type and vendor can be addressed on bus.

After device address is transmitted the bus is released for two clocks. Bus releasing sets STOP condition. During the first clock cycle an addressed device acknowledges by grounding one data line while the second is in high voltage level (START condition). During the second clock cycle the bus speed can be modified by addressed device. Then two bytes of data length are transmitted followed by data.

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Vendor</th>
<th>MAC - IP</th>
<th>Data length</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1B</td>
<td>3B</td>
<td>2B</td>
<td>2B</td>
<td>0-1024B</td>
</tr>
</tbody>
</table>

![Fig. 7 Data frame](image)

When data has already been send, the bus is released again for one clock cycle. Receiving device generates acknowledge by pulling one data line to ground (START condition) and subsequently releases bus by generating STOP condition.

4.2 General Call

There is reserved device address 0x00 defined on the bus. The address 0x00 is used to address each device on bus so it is named General Call. After the device address (0x00) is transmitted and acknowledgement is set, the General Call Command is transmitted instead of data length. Following data length depends on General Call Command.
Unfortunately, detailed description of the General Call Command exceeds range of the article.

4.3 Bus speed change during data frame transmission
Bus speed can be changed even during data frame transmitting after device address is transmitted and acknowledgement is set by addressed device. The bus speed setting is valid only for the data frame and can be set by transmitting (Fig. 8) even receiving device (Fig. 9).

5 Conclusion
The article describes the concept of the cheap bus for home automation. The specified bus uses one unused twisted pair of the UTP-5e cable conductors. The described bus was named SoftBUS and its primary determination is using by microcontrollers. Due to, the maximal specified bus speed is only 1 MBits. Nevertheless, the length of the bus should be up to one hundred meters and number of connected devices is limited only by address space. Bus specification describes physical, link and net level defined by OSI/ISO model.

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